Chapter 4. MONITORING AND FOCUSED RESEARCH PROGRAM DESIGN

Part A, INTRODUCTION AND READER'S GUIDE

Thirty CMARP Workteams developed conceptual models and monitoring and research recommendations based on the information needs of the eight CALFED programs (Ecosystem Restoration, Water Quality, Delta Levees System Integrity Storage, Conveyance, Water Transfers, Water Use Efficiency, and Watershed Management Coordination) and supporting programs (Category III and Conservation Strategy). This chapter summarizes the CMARP Workteam monitoring and research recommendations for each CALFED program. Details of the conceptual models and associated monitoring and research plans appear as appendices to this report. Each section (Chapter 4.A-K) addresses the following:

- CALFED mission, goals and objectives—Lists relevant CALFED goals and objectives addressed by the proposed monitoring. In some cases, monitoring for one CALFED program may fulfill goals and objectives of other CALFED programs.
- Goals and objectives of monitoring plan—Explains how the monitoring plan addresses CALFED goals.
- Monitoring elements—Summarizes the major monitoring elements for each common program.
- Research recommendations—Lists the most important research recommendations for each common program.
- Linkages among program elements—Identifies the linkages between monitoring for a particular CALFED program and the monitoring proposed for other CALFED programs. Identification of the linkages is important for integration of monitoring elements into a cohesive and coordinated program.

The CMARP workteams recommended 640 monitoring elements and 490 research topics. These recommendations are compiled in two large spreadsheets as sub-appendices to the Data Assessment and Reporting Team Appendix (Appendix *VII.I*) and are available on the CMARP web-page. This list includes existing monitoring programs as well as new monitoring recommendations and has not been prioritized.

To provide a broad overview of the monitoring recommendations from all of the CMARP Workteams, Table 4-1 summarizes the recommended monitoring elements and integrates them with indicators proposed by the CALFED ERP Indicators Group. Some workteams, such as Delta Levees System Integrity, also identified indicators. However, for illustration purposes, only the proposed ERP indicators are included in this table. The monitoring elements in Table 4-1 are organized under eight major headings and thirty-three categories. The eight major headings are:

- Biota
- Energetics and Nutrient Cycling
- Geomorphology
- Habitat
- Human Welfare
- Hydrology
- Land use, Water Use & Resource Management
- Meteorology

The categories range from "Birds" to "Bay-Delta Hydrodynamics" to "Water Transfer Effects."

For example, the first category under the "Biota" heading is "Algae & Plankton." The box to the right contains the specific monitoring elements identified for algae, phytoplankton and zooplankton. The listed CMARP workteams for the Water Quality Program (WQ) and Ecosystem Restoration Program (ERP) recommended various subsets of these monitoring elements. The next box to the right contains related indicators proposed by the CALFED ERP Indicators Group.
Future work will include developing and linking indicators to identified monitoring elements for all programs. Indicator selection and development are discussed briefly in Chapter 5.

Table 4-1. Summary of Monitoring Elements recommended by CMARP Workteams and merged with indicators proposed by the CALFED ERP Indicators Group. The monitoring elements are arranged under the general headings of Biota, Geomorphology, Energetics & Nutrient Cycling, Habitat, Human Welfare, Hydrology, Land use & Resource Management, and Meteorology. Each general heading is further organized into categories. Workteams are organized by CALFED Program (**DL:** Delta Levees System Integrity; **ERP:** Ecosystem Restoration Program; **WMCP:** Watershed Management Coordination Program ; **WQ:** Water Quality; **WT:** Water Transfers; **WUE:** Water Use Efficiency). Indicators Group designations are: ARFE=Alluvial River-Floodplain Ecosystem, DE=Delta, SFBE=Greater San Francisco Bay, URFE=Upland River-Floodplain Ecosystem; No designation refers to all systems.

	Category	Monitoring Elements	CMARP Workteams	Proposed Indicators (ERP Indicators Group)
		BIOTA		
1	**Algae & Plankton**	**Algae:** Community survey; biomass relative to nutrients **Phytoplankton:** Biomass; primary productivity; species composition; assemblages **Zooplankton:** Presence/absence; abundance; community; species abundance; biomass; size composition; secondary production; flux	**WQ:** Sacramento River, San Joaquin River, Contaminants **ERP:** Hydrodynamics, Benthic Macroinvertebrates, Fluvial Geomorphology, Estuarine System Productivity, Shallow Water Habitats,Fish X2, Salmon	Trends in abundance, diversity, composition, and distribution of native phytoplankton and zooplankton assemblages (DE, SFBE); Abundance of zooplankton (DE, SFBE); Primary production rates (DE, SFBE)
2	**Birds**	Abundance; distribution; reproduction; species richness/diversity; percent breeding species; reproductive success; percent migrants, genetic diversity, guild structure; clutch size; behavior; sign	**ERP:** Fluvial Geomorphology, Shallow Water Habitats	Trends in abundance, reproductive success, diversity, composition, and distribution of native resident and migratory birds; Population trends of selected listed species
3	**Contaminants (Biota)**	**Algae:** Community assessment **Birds:** Organochlorines, Hg, Se in eggs; Contaminant load **Fish:** bioaccumulation of metals, trace elements, organics, Hg, PCBs, chlorinated insecticides; condition indices; bioassessment surveys; exposure effects; contaminant load **Invertebrate-clams, crustaceans:** bioaccumulation of metals, trace elements, organics, condition indices; contaminant load **Invertebrates:** bioassessment, exposure effects **Small mammals**: contaminant load **Plankton:** Phytoplankton & Zooplankton exposure effects **Vegetation:** contaminant load, bioassessment	**ERP:** Estuarine System Productivity (lower), Shallow Water Habitat, Fluvial Geomorphology **WQ:** Contaminants, Sacramento River, San Joaquin River	Toxicity Concentrations in water and sediment Tissue concentrations Bioassays Biomarkers Bioindicators Contaminant loading
4	**Fish**	**General**: striped bass, splittail, white & green sturgeon, American shad, salmon, steelhead, resident fishes distribution & abundance; relative abundance; community survey; species richness; condition indices; diet; feeding success; biomass; health; growth rate; size class distribution; reproductive success; lamprey spawning; flux; secondary production; species of special concern; distribution of larvae,juveniles,adults in floodplains; emigration past fish ladder; exports from bypasses to rivers; fish screening effects- number salvaged & lost by species; ocean abundance of salmon prey; harvest of wild & introduced species **Delta Smelt:** Adult, juvenile, larval, spawning **Salmon & Steelhead:** ***-Adult:*** ocean conditions; migration timing; straying; pre-spawning mortality; harvest (angler survey, creel survey, ocean); survival; escapement (carcass) surveys; age analysis; redd distribution & stranding rates; egg viability; origin determination; percent hatchery fish in escapement; hatchery fish gamete viability; habitat use; steelhead/rainbow trout allelic variation, dietary analysis,distribution ***-Juvenile***: Outmigration abundance, timing, maturity; distribution vs. streambed complexity; growth; lipid storage; abundance & health indices; stranding rates; smoltification timing; smolt survival; fry emigration	**ERP:** Bay-Delta Productivity (upper), River Resident Fish, Steelhead, Fluvial Geomorphology, Fish X2, Hydrodynamics, Shallow Water Habitats, Delta Smelt, Salmon **WQ:** Contaminants, San Joaquin River, Sacramento River	Trends in abundance, diversity, composition, distribution and trophic structure of natives resident and anadromous fishes; Presence and distribution of native and migratory fish species; Population trends of selected listed species; Number of unnatural barriers interfering with natural movements of native species, flow, sediment & nutrient transport/supply (DE), Cohort replacement & survival rates of selected life stages of certain fish (DE); Invasive introduced species -- Measures of new invasions; Abundance, spatial extent and distribution of selected species; Number of selected species eradicated or exhibiting no net increase in distribution.

	Category	Monitoring Elements	CMARP Workteams	Proposed Indicators (ERP Indicators Group)
5	**Non-Indigenous Species**	Non-indigenous species (invasive fish, invertebrates, animals, plants)- Percent non-indigenous species; presence; distribution; trends; transport & release; new introductions; monitor floating docks & buoys, shallow water margins, small water bodies, small tributary rivers and sloughs, artificial or altered lagoons, shipping facilities & ship exteriors, ship ballast water discharges & seawater system, baitworm seaweed & water packing; Update species keys;	**ERP:** Shallow Water Habitats, Non-Indigenous Species, Fluvial Geomorphology, Resident Fish **WMCP:** Watershed	Invasive introduced species: -Measures of new invasions -Abundance, spatial extent and distribution of selected species -Number of selected species eradicated or exhibiting no net increase in distribution
6	**Invertebrates**	**Benthic:** taxa richness, diversity, EPT taxa & index; dominant species, percent dominant taxon, Hilsenhoff Biotic Index, biomass; size distribution, species composition and abundance; community analysis: secondary production; **Terrestrial:** abundance, diversity, composition, distribution **Aquatic:** distribution; abundance; harvested species' diet & health; mysid abundance	**ERP:** Salmon, Benthic Macroinvertebrates, Fish X2, Estuarine System Productivity, Bay-Delta System Productivity, Shallow Water Habitats **WQ:** Contaminants, San Joaquin River, Sacramento R.	Trends in the abundance, diversity, composition, and distribution of benthic invertebrate assemblages, by functional group (DE, SFBE); Trends in the abundance, diversity, composition, and distribution of riparian insect assemblages, by functional group (URFE, ARFE); Population trends of selected listed species; Secondary production of zoobenthos (DE, SFBE)
7	**Vegetation**	Canopy cover; productivity; biomass; plant architecture; distribution, abundance, richness; riparian structure, stand attributes; upland land cover and structure; vegetation changes after flooding	**DL:** Delta Levees **ERP:** Fluvial Geomorphology, Shallow Water Habitat **WMCP:** Watershed	Trends in distribution, diversity, and structural complexity of native plant associations; Population trends of selected listed species
8	**Terrestrial & Aquatic Species (General)**	Status, distribution, abundance & population trends by taxa in floodplain, riparian, wetland habitats, bypasses & riparian corridors; Extent, distribution, population trends of commercial/recreational species; reproductive success; individual morphometry; harvest of wild & introduced species; wildlife-incidence of disease & deformities; trophic structure; small mammals (biomass, genetic diversity, sign, species richness, trends in diversity, composition & distribution); water conservation & water transfer environmental effects; mitigation for levee improvements;	**DL:** Delta Levees **ERP:** Fluvial Geomorphology, Shallow Water Habitats **WMCP:** Watershed **WT:** Water Transfers **WUE:** Water Use Efficiency	Trends in the abundance, diversity, composition, and distribution of native mammals (URFE, ARFE, DE); Fish and wildlife health; Population trends of selected listed species
		ENERGETICS & NUTRIENT CYCLING		
9	**Energetics & Nutrient Cycling**	Primary productivity, carbon pools; nitrogen fixation; detritus composition & transport; organic carbon input in brackish estuaries; flux of organic carbon, N, P in freshwater/tidal marshes; planktonic nutrient cycling; chlorophyll; vegetation biomass, carbon content & litter accumulation; carbon & nutrients following flood events; microbial communities & production. Ratio of floodplain to river production; export of organic materials from floodplain to river channel [See also nutrients in Water Quality, Sediment, & Soils]	**ERP:** Fish X2, Fluvial Geomorphology, Shallow Water Habitats, Estuarine System Productivity **WMCP:** Watershed **WQ:** Sacramento River, San Joaquin River	Nutrients from salmon carcasses(URFE); Organic input from grazing animals (URFE); Nutrient loading (DE); Ratios of natural to anthropogenic sources of nutrients (URFE); Ratio of floodplain to river production (ARFE); Export of organic materials from floodplain to river channel (ARFE); Percent increase in dissolved N and P after overbank flows (ARFE); Dissolved N and P in groundwater at selected sites (ARFE); Flux of detrital organic matter (DE, SFBE);
		GEOMORPHOLOGY		
10	**Aquifers**	Boundary delineation & compaction; regional and local mapping of hydrogeologic boundaries; thickness and degree of confinement	**WT:** Water Transfers	
11	**Channel**	Bathymetric surveys; structural complexity; channel & bank stability & erosive resistance; streambed complexity; cross-sectional profile, hydraulic geometry, meander geometry, longitudinal profile, channel density, network order, channel changes after flooding; number freely meandering river miles;	**DL:** Delta Levees **ERP:** Hydrodynamics, Salmon, Benthic Macroinvertebrates, Steelhead, Shallow Water Habitats,Fluvial Geomorphology **WMCP:** Watershed	Mean width of available meander corridor (ARFE); Percent of river length not constrained by constructed levees (ARFE); pool to riffle ratio (URFE); Inter-annual comparison of fluvial geomorphic features (URFE); Percent of river miles exhibiting naturalistic meandering (ARFE); Linear distance of channels per unit area (DE); Proportion of 1st, 2nd, 3rd order channels/ unit area(DE); Bank slope(DE)

	Category	Monitoring Elements	CMARP Workteams	Proposed Indicators (ERP Indicators Group)
12	**Land**	Subsidence (Delta island, Delta levees, Central Valley); land surface altitude; topographic/geologic characterization; landslides; floodplain features, surface roughness, basin topography	**DL:** Delta Levees **ERP:** Fluvial Geomorphology **WT:** Water Transfers **WMCP:** Watershed	Difference in percent of area flooded during MHHW versus MLLW (DE)
13	**Sediment**	**Chemistry:** ionized ammonia, total sulfides, total organic carbon, total nitrogen; phosphorous; micronutrients; salinity; pH; redox potential; conductivity **Contaminants:** Se, organics, organochlorines, resuspension mercury; toxicity; trace elements & metals; **Physical:** Texture; composition; grain size;particle size distribution; bulk density; deposition & resuspension dynamics; floodplain, bank, & channel deposits; organic matter; depth of detritus; substrate permeability; sediment production background rates; bioturbation depth; [See Water Quality for suspended sediments]	**ERP:** Estuarine System Productivity, Salmon, Fluvial Geomorphology, Shallow Water Habitats, Hydrodynamics, Benthic Invertebrates **WQ:** Contaminants **WMCP:** Watershed	Bedload movement (URFE); Sediment particle size and distribution (URFE, ARFE); Net change in depth per unit time of unconsolidated sediment (URFE, ARFE); Amount of coarse sediment delivered (as a proportion of pre-dam) (ARFE); Lateral exchange: river to floodplain (ARFE); Inter-annual comparison of fluvial geomorphic features (ARFE); Marsh plain & mudflat elevation relative to sea level (DE, SFBE); Change in area of Delta islands and islets (DE); Net sediment accretion rate relative to rate of sea-level rise at subtidal and intertidal sites (SFBE);
14	**Soils**	**General:** stability and erosive resistance; horizontal & vertical accretion & erosion; C, P, N, micronutrients, salinity, redox, pH; moisture; organic matter, particle size distribution; contaminants **Peat & organic:** oxidation; gradation, organic matter content, moisture, void ratio, compressibility, vertical & horizontal extent;	**DL:** Delta Levees **ERP:** Fluvial Geomorphology, Shallow Water Habitat **WMCP:** Watershed Management	
		HABITAT		
15	**Habitat**	**General**: habitat spatial extent, configuration, distribution, connectivity; patch classification, size frequency, diversity, temporal variability; habitat metrics & quality; tidal wetlands with natural flooding; total shoreline length; floodplain habitat proximity to topographic features, e.g. location of the thalweg & littoral zone; aerial extent of wetlands and seasonally wet environments; riparian habitat delineation & areal extent; detritus & debris; **Vegetation**- horizontal cover and vertical structure; canopy cover; riparian forest width, height, density relative to water temperature; changes after flooding **Channel:** river habitat vs. fish assemblage; floodplain inundation, frequency & duration; channel changes after flooding; steelhead & salmon rearing habitat & spawning habitat investigations & restoration; flooding effects on salmonid habitat; **Stressors**: impacts due to levee improvements & compensatory mitigation; occurrence of unnatural barriers interfering with movements of native species; water transfer & water conservation environmental effects; response to levee breeches/removal	**DL:** Delta Levees **ERP:** Steelhead, Fluvial Geomorphology, Salmon, Shallow Water Habitats, Benthic Macroinvertebrates **WMCP:** Watershed **WT:** Water Transfers **WUE:** Water Use Efficiency	Extent and distribution of patches of all natural habitat types; presence and distribution of species requiring multiple habitats; Abundance, distribution, and recruitment rate of large woody debris (URFE); Shaded riverine aquatic habitat (URFE); Diversity of flow velocity (URFE); Distribution and extent of floodplain habitats (ARFE); Distribution and extent of littoral zone (ARFE); Percent of river length not constrained by constructed levees (ARFE); Connectivity of riverine channels to wetlands (DE); ; Length of river channel obstructed by artificial barriers; Length of riparian corridor unobstructed by artificial barriers;
		HUMAN WELFARE		
16	**Flood**	levee inspection, high water monitoring & staking; flood emergency response status; flood fighting support; levee technical assessment	**DL:** Delta Levees	
17	**Health**	Risk assessment for Hg, Se; Mitigation of Se inputs into ducks, crabs & fish; drinking water impacts	**WQ:** Contaminants	Toxicity: Concentrations in water, sediment, tissue, bioassays, Biomarkers, Bioindicators, Contaminant loading;
18	**Population/ Demographics**	Population; population within water service area boundaries;	**WT:** Water Transfers **WUE:** Water Use Efficiency	

	Category	Monitoring Elements	CMARP Workteams	Proposed Indicators (ERP Indicators Group)
19	**Socio-Economic**	**General**: Income; rural businesses sales & employment; social & economic values related to community involvement, watershed management, recreation, habitat extent & species diversity; third party effects of water transfers and conservation; recycled water expenses & use benefits; delta operations outages, power operations & costs **Agriculture**: Value of agricultural output; agricultural employment; labor force and unemployment; social and economic values related to agricultural practices	**WMCP:** Watershed **WT:** Water Transfers **WUE:** Water Use Efficiency	
		HYDROLOGY		
20	**Bay-Delta Hydro-dyamics**	3D-Hydrodynamic Model; X2; delta export rates; channel tidal flows; historical bay-delta hydrodynamics studies; horizontal current patterns; ocean currents; sea level rise; shallow water hydrology; tidal prism conservation; hydroperiod; tidal regime; tidal prism; tidal time series flow; net tidally averaged flow; upwelling; water depth;	**DL:** Delta Levees **ERP:** Hydrodynamics, Salmon, Shallow Water Habitats, Estuarine System Productivity **WT:** Water Transfers	Water movement and vertical mixing at select locations throughout Bay (SFBE); X2 location (SFBE); Salinity at selected locations in the Bay (SFBE);
21	**Flow**	Adequate streamgage network; Daily flow; depth; diversions & withdrawals; Delta operations flow requirements; Delta inflow & outflow; installation & removal of barriers; flow gate operation; inflow rate; river time series; stage (height); discharge; velocity; velocity profiles; vertical hydraulic gradient; flood frequency & inundation; changes due to setback levees; peak flows; pulsing, flooding regime; floodplain inundation, frequency & duration; characterization of low flows; historic streamflow & stage data; hydroperiod; flow predictions from snowmelt & runoff models-runoff; evaporation; infiltration	**DL:** Delta Levees **ERP:** Fluvial Geomorphology, Estuarine System Productivity, Salmon, Hydrodynamics, Shallow Water Habitat, Benthic Macroinvertebrates, Steelhead **SC:** Storage & Conveyance **WMCP:** Watershed **WQ:** Contaminants, San Joaquin River **WT:** Water Transfers	Minimum base flows (URFE, ARFE); Seasonal shifts in river level (URFE, ARFE); Measures of variability (URFE, ARFE); Geographic distribution of flows (ARFE); Delta outflow (DE); X2 location (SFBE); Salinity at selected locations in the Bay (SFBE); Minimum surface area of floodplain inundated at least once every 2 years and every 10 years (ARFE); Flood duration (mean and variability) (ARFE); Mean annual frequency of floods (ARFE); Composite measures for freshwater flow rates, water residence time, and flow direction for selected channels (DE); Flows of tributaries mimic pattern of unimpaired flow (DE);
22	**Groundwater**	Discharge & recharge; levels; movement; water quality; sources; wetland storage & streambank storage; net infiltration	**DL:** Delta Levees **ERP:** Fluvial Geomorphology **WMCP:** Watershed **WT:** Water Transfers	Depth of water table (ARFE); Soil moisture levels, laterally from banks (ARFE); Characteristic plant communities (ARFE); Width of riparian corridor (ARFE)
23	**Reservoirs**	Conditions; water quality; temperature; storage; suspended sediments deliver & types to impoundments	**ERP:** Steelhead **WMCP:** Watershed **WT:** Water Transfers	
24	**Water Quality**	**Contaminants**: Pesticides & other organic chemicals, MTBE, bromide, dissolved & total organic carbon, THMFP, dissolved & total trace metals including mercury & methylmercury, selenium, pathogens, nutrients. Contaminants & nutrient loading from sources such as dredging operations, wastewater discharge, cannery effluent, urban runoff, dairies, farms & rangeland. Aquatic toxicity to invertebrates, algae, fish. **Chemistry:** Alkalinity; pH; conductivity; dissolved oxygen; hardness; major ions; C, P, N, micronutrients; nutrients-organics; BOD; salinity; TDS; total organic carbon; strontium in steelhead spawning streams; chlorophyll **Physical:** Light attenuation; irradiance; total suspended solids; turbidity;temperature; suspended sediment flux,bedload,solute load	**DL:** Delta Levees **ERP:** Fluvial Geomorphology, Benthic Macroinvertebrates, Fish X2, Salmon, River Resident Fish, Estuarine System Productivity, Steelhead Hydrodynamics; Shallow Water Habitat **WMCP:** Watershed **WQ:**Contaminants, Sacramento River, San Joaquin River, Drinking Water **WT:** Water Transfers	Toxicity: Concentrations in water and sediment, Tissue concentrations, Bioassays, Biomarkers, Bioindicators, Contaminant loading; Salinity at selected locations throughout the Delta (DE); Dissolved oxygen; Turbidity-suspended solids; Nutrients (N, P, C); Salinity/TDS

	Category	Monitoring Elements	CMARP Workteams	Proposed Indicators (ERP Indicators Group)
		LAND USE, WATER USE & RESOURCE MANAGEMENT		
25	**Land use**	**General:** Land use, trend analysis, history, intensity, management practices; presence & type of human activities near streams, riparian areas & habitats; logging; mining; point sources of sediments & contaminants; urbanization; roads & road-building; wildfire & fire suppression; watershed improvement practices; program personnel turn over & funding; shoreline development; **Agriculture:** Number & size of farms; crop patterns; land use surveys including irrigation method by crop; grazing; management practices; chemical applications; pesticide management effectiveness;	**ERP:** Fluvial Geomorphology, Shallow Water Habitats **WMCP:** Watershed **WQ:** Contaminants **WT:** Water Transfers **WUE:** Water use efficiency	
26	**Levees & Impound-ments**	**Levee**: Levee cross-sections, profiles & maintenance quality inspections; levee miles or islands/tracks meeting minimum PL84-99 standard, with enhanced flooding protection, with seismic upgrades, with subsidence control measures; assessment of set-back levee restoration efforts; [see also Geomorphology] **Impoundments;**	**DL:** Delta levees **ERP:** Fluvial Geomorphology **WMCP:** Watershed	
27	**Water Deliveries & Transfers**	Surface water; recycled water; history of water transfers; water transfers among agencies within the projects	**WMCP:** Watershed **WT:** Water Transfers **WUE:** Water Use Efficiency	
28	**Water Recycling**	Amount produced/used in supplier service area, quality of source water & recycled water; wastewater collected/treated; wastewater discharge; water quality effects on recycled water production & usage	**WUE:** Water Use Efficiency	
29	**Water Use**	**Agriculture:** EWMP implementation; land use/acreage by irrigation methods; irrigation amounts & efficiency; real time Eto; crop coefficients; length of canals & laterals; canal seepage; reduction in applied water & groundwater depletion; surface & subsurface drainage water & ground water reuse; delta water use surveys; **Environmental:** Operational commitments to fisheries; wetland restoration evapotranspiration rates **Urban:** Applied water reduction; BMPs; commercial, industrial, & institutional customer data; landscape irrigation efficiency; groundwater depletion; interior water use; irrigated landscape acreage surveys; water management plans; water use per capita data by customer class, water district, hydrologic region; water use efficiency estimates; seasonal & peak water use; water audits & leak detection	**WMCP:** Watershed **WUE:** Water use efficiency	
		METEOROLOGY		
30	**Air**	Mercury deposition; organochlorine source loading; relative humidity; temperature; wind speed & direction	**ERP:** Estuarine System Productivity **WQ:** Contaminants	
31	**Precipitation**	Amount, timing & form; snow-pack & snow-melt dynamics, sunlight, weather, weathering	**ERP:** Estuarine System Productivity **WMCP:** Watershed	

Chapter 4, Part B. Ecosystem Restoration Program Plan

Goals of the Ecosystem Restoration Program Plan (ERPP)

The mission of the CALFED Bay-Delta Program is to develop a long-term comprehensive plan for the restoration of ecosystem health and improve water management for beneficial uses of the Bay-Delta system. The ERPP has been developed to address problems related to ecosystem quality. Ecosystem goals developed as part of the Strategic Plan for Ecosystem Restoration (1998) will guide implementation of the program. These strategic goals include:

1. Achieve large, self-sustaining populations of at-risk native species dependent on the Delta and Suisun Bay, support similar restoration of at-risk species in San Francisco Bay and the watershed above the estuary, and minimize the need for future endangered species listings by reversing downward population trends of non-listed native species.
2. Rehabilitate natural processes in the Bay-Delta estuary and its watersheds to support, with minimal ongoing human intervention, natural aquatic and associated terrestrial biotic communities, in ways that favor native members of those communities.
3. Maintain and enhance populations of selected species for sustainable commercial and recreational harvest, consistent with goals 1 and 2.
4. Protect or restore functional habitat types throughout the watershed for public values such as recreation, scientific research, and aesthetics.
5. Prevent establishment of additional non-native species and reduce the negative biological and economic impacts of established non-native species.
6. Improve and maintain water and sediment quality to eliminate to the extent possible, toxic impacts to organisms in the system, including humans.

The CALFED Ecosystem Restoration Program (ERP) proposes to reach these goals through restoration of the physical and ecological processes associated with the formation and maintenance of the habitats required by the diverse species dependent on the Bay-Delta and its associated watersheds. The ERP proposes to achieve this restoration through an ambitious program including a wide variety of actions taken in the context of adaptive management. The core idea behind adaptive management is to treat management actions as scientific experiments. This requires that the effects of each management action be monitored and the data assessed to determine the success of the action and modify subsequent actions to achieve greater success, if possible, in response to the knowledge gained. Also, the ERP recognizes that management of human activities is an integral component of ecosystem management. Thus, actions undertaken as part of other CALFED programs concerned with water quality, water supply reliability; and levee integrity must be closely linked to ERP.

As an initial step in achieving the first goal, CALFED is developing a comprehensive Conservation Strategy (Conservation Strategy, 8 Oct. 1998 draft). The Conservation Strategy addresses all Federal and State listed, proposed, and candidate species that may be affected by the CALFED Program actions and integrates enhancement and mitigation efforts that will benefit the species and the habitats that support them. As part of the conservation and protection of these species and habitats, the Conservation Strategy specifies monitoring and reporting needs that must be met by the broader CALFED monitoring and adaptive management programs. The

Conservation Strategy is especially important because it will form the foundation for compliance with the California Endangered Species Act, the Federal Endangered Species Act, the Natural Community Conservation Planning Act, and other regulatory requirements. Such compliance will be necessary for the implementation of CALFED programs and associated monitoring and research activities.

OBJECTIVE OF THE ERP PORTION OF CMARP

The complex and ambitious adaptive management program proposed by CALFED, and ERP in particular, requires a significant investment in monitoring and research activities. Long-term, system-wide, baseline monitoring data are needed to determine if the overall goals are being met.

- Monitoring is needed to determine the effects and degree of success of specific actions and projects.
- Focused research is needed to increase understanding of ecological processes and consequently reduce uncertainty regarding the outcome of actions.

As outlined in the Strategic Plan for Ecosystem Restoration (1998), all of these activities should be undertaken within a framework of:

- developing conceptual models,
- developing testable hypotheses,
- testing the hypotheses by conducting focused research, and
- learning from management actions, which would lead to improvement of conceptual models and more refined management actions.

The purpose of the ERP portion of the CMARP (ERP-CMARP) is to present an initial concept of the monitoring and research program required to implement, assess, and improve the ERP as adaptive management proceeds. The plan includes monitoring of physical processes that may change in response to CALFED actions, such as river flow below dams that can affect fluvial geomorphic processes. The plan includes monitoring of habitats affected by those processes, such as channel form and riparian vegetation. The plan also includes monitoring of the species dependent on those habitats, with additional emphasis on species of high concern. The final ERP-CMARP will also be designed to fulfill the monitoring and assessment needs of the Conservation Strategy, once those needs have been finalized.

The plan is programmatic in scope because a sequence of actions has not yet been defined. Thus, the plan is flexible and can be modified as the sequence of CALFED actions is implemented. For example, ongoing discussions in the Diversion Effects on Fish Team (DEFT) include the concept of a comprehensive program of real-time monitoring of fish species of concern to aid in management of an environmental water account. Such a program cannot be designed until the data needs of the entity managing the environmental water account are known. Once the requirements are known, a program can easily be designed and incorporated into the CMARP framework.

Small groups of experts (work teams) were asked to design discrete portions of the plan. Each work team was asked to provide a conceptual model, a monitoring program, and a program of focused research for their topic (Appendices *VII.A1-14*). The short time available for developing the plans precluded the participation of many interested scientists and did not allow for outside review and revision of the plans. The lack of full involvement with the stakeholder community suggests that their reviews will be necessary before proceeding with refinement of the program. Thus, the initial framework for ERP-CMARP presented here will continue to be revised and improved as CMARP moves into the implementation phase. This process will likely involve new work teams with a wider range of stakeholder membership. These teams will develop more comprehensive or alternative conceptual models and identify the research needed to test the underlying hypotheses critical to determining which conceptual models should guide development of CALFED management actions.

Work team assignments were made before the Strategic Plan for Ecosystem Restoration (1998) was available, so the goals and objectives listed in individual appendices may not exactly match those presented in the body of this report. The Conservation Strategy (1998) was also unavailable to the work teams and so is not explicitly addressed; however, the need to monitor special-status species was stressed in many of the reports.

The work team assignments included requests for estimated costs, appropriate indicators, and prioritization of monitoring and research elements; however, these items were not required and response was variable. The work teams were instructed not to submit "wish lists" and to be practical with regard to recommendations. Realistically, it is inevitable that logistic and monetary constraints will limit the scope of CMARP from what is proposed in the appendices. Prioritization of the monitoring and research elements within ERP-CMARP and among the portions of CMARP related to other CALFED Common Programs will likely be a sensitive process requiring discussion among the CALFED stakeholders as CMARP implementation proceeds.

The plan components are divided into those concerned with **river systems** and those concerned with the **Bay-Delta system**. This division is arbitrary but does correspond with many changes in issues and monitoring and research methods used to study them. Clearly, the river and Bay-Delta components will be closely integrated in the actual design and implementation of CMARP. The ERP primarily limits consideration of river issues to the stream reaches downstream of the major foothill dams or equivalent elevations on undammed streams. Upstream reaches of rivers are covered by the CALFED Watershed Management Coordination Program; however, several other work teams also included upstream river reaches in their plans to some degree. Terrestrial issues were not adequately addressed in this initial ERP-CMARP. Development of these aspects of the program should continue in close cooperation with the Watershed Management Coordination Program. The major components of monitoring proposed for each type of system are presented below.

ERP-CMARP PROGRAM COMPONENTS

Products of the ERP-CMARP work teams are summarized in the following sections. The content varies but generally includes a brief justification for the particular monitoring and research component, major monitoring and research needs, and a listing of any proposed indicators. Refer to the individual appendices for more detail. Linkages among the various ERP-CMARP plans are discussed below, as are linkages between ERP-CMARP and other Common Programs and linkages between ERP-CMARP and existing monitoring and research programs.

RIVER SYSTEMS

Fluvial Geomorphology, Hydrology and Riparian Issues (Appendix *VII.A.12*)—The objective of many CALFED actions is to re-establish natural flow patterns and associated habitat processes in regulated streams to improve habitat for anadromous fishes, resident fishes, other aquatic organisms, and terrestrial plants and animals. These processes include such things as stream meander, sediment recruitment and transport, floodplain inundation, stream hydrology, and riparian forest succession. These processes are understood in a general sense; however, many concepts of fluvial geomorphology are best applied to free-flowing streams and the concepts may have to be adapted for regulated streams. The degree to which natural function can be restored to systems in the CALFED solution area is unknown in some cases because present conditions have been so altered from natural conditions. A monitoring and research program is needed to assess the success of CALFED actions and improve understanding of fluvial geomorphology (which includes hydrologic processes) and riparian processes.

The monitoring recommendations emphasize the gravel-bed reaches of the streams where anadromous fishes spawn and rear and where most other native fishes are found. Additional emphasis on soft-bottomed reaches may be appropriate as the program develops. The monitoring program includes:

- Periodic stereoscopic aerial photography of all significant streams of interest. Photography should be repeated approximately every five years or after significant flows. Fluvial geomorphic processes are largely driven by large flows; thus, floods may result in significant changes that should be documented as soon as possible. Photographic analysis will provide data at scales ranging from the landscape level to the project-specific level, including topography, channel form, stream width, sinuosity, general habitat types at several scales of detail, and riparian vegetation.
- Comparison of aerial photographs taken during high and low flows to define the extent of floodplain habitat available. In addition, new or supplemental photography might be required to document effects of management actions such as levee setbacks or channel modifications.
- Detailed measurements at 40-50 long-term monitoring sites throughout the CALFED solution area. Two types of sites are needed--geomorphic and riparian. Ideally, a single site will serve both functions. The sites will serve as long-term monitoring sites for baseline conditions or as comparison sites for projects within the same or nearby reaches of stream. Geomorphic measurements include detailed channel morphology, stage-discharge curves (the relationship between water level and stream flow), floodplain morphology, and substrate composition as important variables. Riparian measurements include tree species composition and trunk diameter, shrub species composition and basal area, percent cover by herbaceous species, and various other growth and productivity measures.
- Monitoring of geomorphic processes, riparian plants, and animals. A plan for monitoring of birds is provided. General guidelines, compatible with those proposed for the Watershed Management Coordination Program, were also developed for integrated monitoring of habitats, species, and ecological communities. Plans for river resident fishes, including anadromous lampreys, and anadromous salmonids were designed by separate work teams (below).
- Monitoring of physical habitat and biota in floodplain areas and flood bypasses.
- Review and assessment of adequacy of the existing network of stream flow gages. Accurate flow measurements are essential to the calculation of many hydrologic parameters and interpretation of the monitoring data gathered.

Research or assessments of existing data are needed in several areas (see Appendix *VII.A.12* for justifications).

- Test a methodology for assessing the effect of water development on flow regime.

- Compile and assess temperature data and existing temperature data collection activities.
- Improve understanding of river-groundwater exchange processes.
- Improve understanding of groundwater (hyporheic zone) ecology.
- Improve understanding of riparian vegetation recruitment dynamics.
- Assess the importance of floodplain habitat to fish and other aquatic and terrestrial animal populations.

River Benthic Macroinvertebrates (Appendix *VII.A.13*) – Benthic macroinvertebrates are important as food for various life stages of many anadromous and resident fishes and terrestrial animals. Bioassessments of benthic macroinvertebrate communities are commonly used tools for monitoring of water quality and evaluation of watershed condition. Individual species of benthic macroinvertebrates are sensitive in varying degrees to water temperature, dissolved oxygen, sedimentation, scouring of the streambed, nutrient enrichment, and chemical and organic pollution. Benthic macroinvertebrates also have intrinsic value as an important component of ecological diversity. Benthic macroinvertebrate monitoring is primarily included in CMARP as a bioassessment tool for detection of changes in the stream environment resulting from CALFED actions. Secondarily, changes in the diversity or abundance of this resource could have effects on higher trophic levels, particularly fish.

The monitoring program should have a number of characteristics.

- The suggested scale of monitoring is the watershed, which requires coordination between ERP and the Watershed Management Coordination Program.
- Adopt specific protocols for site selection, sampling methodology, and sampling frequency (see Appendix *VII.A.10* for suggestions).
- Characterize physical and water quality conditions at each site as completely as possible, including at a minimum: water temperature, pH, turbidity, specific conductance, water depth, water velocity, substrate characteristics, and canopy cover.
- Determine relationships between species abundances and biological metrics of community structure with watershed characteristics and physical and chemical parameters.
- Develop appropriate models or indices to provide a standardized measure of the condition of the benthic macroinvertebrate community.

Simultaneously with the monitoring effort, several research topics should be pursued.

- Improve knowledge of the taxonomy and distribution of California benthic macroinvertebrates to better understand the species diversity present in the study area. This research will also provide information on exotic species.
- Determine the sensitivity of western species of benthic macroinvertebrates to various types of environmental degradation. Existing research emphasizes streams in the eastern United States.

Several metrics of benthic macroinvertebrate communities are commonly used as indicators in bioassessments. These metrics may also serve as useful indicators of benthic macroinvertebrate community condition for ERP and include taxa richness, Shannon Diversity Index, EPT taxa (total number of distinct taxa in the insect Orders Ephemeroptera, Plecoptera, and Trichoptera), EPT Index (proportion of total number of individuals in EPT taxa), Modified Hilsenhoff Biotic Index (HBI), and Percent Dominant Taxon (PDT) (the percentage of total individuals represented by the most dominant taxon).

River Resident Fishes (Appendix *VII.A.10*)—The emphasis of the ERP on ecosystem management, ecosystem processes, and preventing the decline of currently unlisted species of fish and other taxa will require monitoring and research on river resident species (including anadromous lampreys). Fish communities, similar to benthic macroinvertebrates, may be used as bioindicators of environmental conditions. Resident fishes, both native and introduced, respond seasonally and annually to environmental conditions including flow regime, physical habitat, water quality, and interactions with other species. The monitoring program will simultaneously build the long-term data base required to assess the affects of CALFED actions on resident fish populations and provide the information needed to continue refinement of the conceptual models and increase understanding of ecological processes.

The work team proposed a long-term, geographically extensive program of monitoring to assess the distribution and relative abundance of native and introduced river resident fish species and to detect new introduced species as they enter the system.

- Monitor river resident fishes in all streams being monitored for anadromous fishes with cooperative sampling whenever possible. Additional monitoring should be conducted on a prioritized set of the remaining streams and will depend, to some extent, on proposed management actions and the ability to locate monitoring sites at locations where other monitoring is occurring.
- Develop specific sampling protocols for site selection, sampling methodology, and sampling frequency (see Appendix *VII.A.10* for suggestions).
- Evaluate additional measurements that will benefit both monitoring and research, including assessment of fish condition/health, aging of fish, diet analysis, in addition to the collection of routine information such as species identification, counts, lengths, and weights.

Several areas of research would be useful in the interpretation of the monitoring data and in understanding the responses of resident fishes to management actions.

- Compile existing data and conduct research as needed on the life history and physiology of resident species to better understand their responses to environmental conditions.
- Clarify the population structure (genetics) of species of concern.
- Evaluate the development of an Index of Biotic Integrity or similar index as an indicator of resident fish community condition.
- Evaluate techniques for assessment of fish condition/health.
- Experimentally test causal relationships suggested by monitoring data and observational studies.
- Document the sources and effects of new exotic species as needed.
- Assess the effects of commercial or recreational exploitation as appropriate for selected native and exotic species.

Several possible indicators were suggested for resident fishes. An Index of Biotic Integrity or similar multimetric index could be developed. Percentage of native fish and percentage of intolerant fish (species sensitive to environmental stress) are other possible general indicators. Measurements of fish health/condition can also serve as good general indicators. Map presentations of the geographic distribution of the various fish communities can provide a useful summary of complex fish community data.

Chinook salmon (Appendix *VII.A.8-9*) – Chinook salmon are probably the most studied fish in the Central Valley. Thus, the conceptual models, monitoring, and research proposed for this species are the most detailed of any presented for the monitoring elements concerning river systems. The high level of concern reflects the recreational, commercial, and aesthetic value of the species and the Federal or State listing of the various runs. The chinook salmon work team considered steelhead needs in their plan but a separate steelhead plan (below) was also prepared to highlight the needs for proper understanding of steelhead needs. Restoration of salmon runs is a major objective of CALFED. Monitoring and assessment of the effectiveness of CALFED actions is essential to evaluating success.

The conceptual model focuses on the major life stages of the fall-run chinook salmon and is based on an extensive review of the existing literature and other information on Central Valley chinook salmon. The conceptual model identified key issues for each life-stage.

- Upstream migration of adults – straying, delayed migration, egg viability, migration barriers, and prespawning mortality.
- Spawning – altered flows, degraded channel complexity, high water temperatures, gravel recruitment, harvest and harassment, and altered genetics due to hatchery fish.
- Incubation and emergence – elevated water temperatures, fine sediment intrusion, gravel recruitment and instream gravel mining, intrusion of oxygen-poor groundwater into redds (nests), excessive gravel mobilization during high flows, and reduced habitat complexity.
- Juvenile rearing – stream flow and interactions with floodplains, elevated water temperatures, contaminants, food supply, and disease.
- Juvenile migration – stream flow, predation, unscreened diversions, stranding, and water temperatures. Juvenile migration through the Bay-Delta is covered by a separate monitoring element below. The work team also noted that ocean residence can have very important effects on chinook salmon populations.

The suggested monitoring elements were extensive and covered each life stage separately.

- Adult monitoring using carcass surveys on streams not included in existing programs, evaluation of new or additional methods for estimating adult abundance, and analysis of scales and otoliths to verify age structure of the runs.
- Monitoring of spawning activity should include documentation of the distribution of redds within and between riffles so the extent of spawning habitat can be determined and under-utilized habitat identified.
- Where spawning habitat restoration projects are funded and unsuitable intragravel water quality exists, monitor intragravel dissolved oxygen concentration, intragravel water temperatures, substrate permeability, and vertical hydraulic gradient.
- Assess the overall abundance and health of juvenile salmon annually, using a variety of techniques at monthly intervals from February through June in cooperation with existing programs.
- Monitor juvenile survival in both the river and the Bay-Delta system. Techniques suggested to monitor river survival include mark-recapture studies of hatchery and (if available) wild fish. Several different group sizes should be used for releases and, in streams where outmigrants of appropriate size are available, radio tagging should be used.
- Monitoring of ocean conditions such as ocean harvest, ocean currents, and prey abundance, was also mentioned as an important activity.

Research topics derived from the assumptions and hypotheses forming the basis of the conceptual models are summarized under the following general categories:

- effects of fluvial geomorphology,
- effects of predation,
- effects of water temperature,
- factors effecting smolt survival,
- instream flow studies,
- genetic evaluations of stock structure,
- adult tagging studies,
- creel surveys,
- effects of contaminants, and
- factors affecting egg incubation.

Five possible indicators were identified as trends in:
1. naturally-produced salmon and steelhead measured as sport harvests and escapement to rivers and the ocean,
2. the number of "crashes" (catastrophic loss of a brood year) due to unsuitable environmental conditions,
3. the egg-to-fry survival of naturally-produced salmon and steelhead,
4. the number of naturally-produced juvenile salmon and steelhead migrating out of rivers, and
5. the survival of naturally-produced juvenile salmon and steelhead migrating through the rivers and Delta.

Steelhead (Appendix *VII.A.11*) – Compared to chinook salmon, Central Valley steelhead have received relatively little study. In the past, it has been assumed that steelhead respond to environmental stresses in the same way as chinook salmon. The conceptual models prepared by the chinook salmon teams apply generally to steelhead because the species share an anadromous life history but there are some significant differences, especially in population structure and dynamics. Most importantly, however, are differences in the severity of impacts of stressors common to the two species (particularly those dealing with flow and temperature), which can be greater for steelhead because of the longer period of freshwater rearing by juveniles. The primary stressor identified for steelhead was large-scale loss of spawning and rearing habitat. Juvenile steelhead must rear in fresh water for one year or longer; therefore, water temperatures must remain in the tolerable range for the entire year. This is often not the case during late-summer and fall below the major dams. The status of steelhead populations and their response to CALFED actions must be monitored because the species, a member of the native fish community, is Federally listed as threatened and supports a valuable recreational fishery.

Six major knowledge gaps require either new monitoring and assessment programs or enhancements to ongoing anadromous fish monitoring programs:
- Current distribution and abundance of naturally-spawning populations.
- Specific spawning and rearing habitat requirements and assessment of existing habitat.
- Genetic and population structure of Central Valley steelhead.
- Feasibility of providing access and restoration of potential habitat currently above impassable dams.
- The degree of straying of hatchery steelhead and the effects of straying on naturally-spawning populations. Assessing these effects may require documentation of straying in natural populations as well.
- Effects of water project operations in the delta/estuary.

The suggested comprehensive monitoring plan, for application in the tributary streams, mainstem rivers, and the Delta, as appropriate, has two primary components--habitat monitoring and population monitoring. Specific recommendations include:
- habitat typing and mapping,
- stream flow and temperature monitoring,
- identification of other stressors important in specific situations (e.g., sedimentation), and
- population monitoring for several life stages, including spawning adults, rearing juveniles, and emigrating juveniles.

Changes in abundance, timing of life stage, and habitat availability, at each life stage, were identified as indicators by the work team. A detailed list of specific monitoring questions to be addressed by the program was also provided. In many respects the monitoring program proposed by the work team also serves as a research component because so little is known about Central Valley steelhead.

BAY-DELTA SYSTEM

Hydrodynamics (Appendix *VII.A.4*) – In recent years, workers in the Bay-Delta system have come to recognize that understanding hydrodynamics, the movement of water through the system, is central to understanding how sediments, salts, nutrients, contaminants, other chemicals, and organisms are distributed. This task is complicated by the physically complex and tidally driven nature of the estuary. In essence, hydrodynamics encapsulates the physical processes essential to the creation, maintenance, and evolution of Bay-Delta habitats that are used by and determine the distribution of organisms. Monitoring and understanding Bay-Delta hydrodynamics is essential to assessment and refinement of CALFED actions affecting the physical structure of existing channels and water management.

The conceptual model for Bay-Delta hydrodynamics must consider two pivotal concepts that account for the complexities involved in hydrodynamic monitoring and research.

- Various temporal scales--include the tidal (about daily) time scale, the fortnightly spring-neap tidal cycle, and annual and longer time scales.
- Spatial variability--Sources include the physical complexity of Delta channels, the interaction between shoals (shallows) and deep channels, longitudinal salinity structure, horizontal stratification in Central Bay, semi-isolation of South Bay, and the interaction of shoals and channels with marshes and intertidal mud flats.

A variety of new monitoring programs were suggested in addition to ongoing programs.

- Deploy bottom salinity/temperature sensors to accurately define X2 (X2 is a regulatory tool defined as the distance in kilometers up the axis of the estuary to where the tidally-averaged near-bottom salinity is 2 psu).
- Deploy various sensors to estimate fluxes (movements) of water and other materials at key points in the Bay-Delta system.
- Monitor water flow with a before and after monitoring design linked to CALFED actions and choice of the preferred alternative.
- Deploy various sensors in selected shallow-water regions to determine interaction of deep and shallow-water regions.
- Monitor deposition and resuspension of sediments.
- Conduct periodic measurements of bathymetry (channel geometry).
- Continually utilize and update hydrodynamic models to improve understanding of the system.

Research topics stress specific issues important to improving the ability of models to confidently predict changes in hydrodynamics that might occur in response to CALFED actions.

- Determine net transport through major cross-Delta connections (e.g., Georgiana Slough).
- Resolve the hydrodynamic basis and accuracy of the concepts supporting QWEST and carriage water.
- Determine the dependence of water residence time on tidal and flow conditions in shallow water regions (e.g., Franks Tract).
- Quantify the degree of cross-sectional mixing in channels and the influence of size, shape, and connections with other channels.

- Conduct research into all aspects of the hydrodynamics of shallow water areas, including processes within shallows and between shallows and deeper channels.
- Determine transport processes and flow structure in Suisun Bay and areas downstream.
- Determine fluxes of materials and organisms in areas of interest.
- Determine processes of sediment deposition and resuspension.
- Conduct numerical modeling.

Several possible indicators were identified for hydrodynamic processes. The proposed calculations of fluxes of material and organisms at various points in the system might serve as indicators, especially the fluxes in waterways of high interest (e.g., Delta Cross Channel or various points in Old River). Inferred mass fluxes similar to QWEST or cross-Delta flow might be possible. Water level at the Golden Gate or X2 could also serve as indicators. The usefulness of these indicators to ERP will depend on linking them to important ecosystem process such as primary productivity or transport of larval fish to favorable nursery areas.

System Productivity at Lower Trophic Levels (Appendix *VII.A.5*) – This work team addressed a number of issues including physical processes, primary production by phytoplankton and benthic plants, the microbial food web, zooplankton and macrozooplankton (mysid shrimp and amphipods), benthic macroinvertebrate communities, exotic species, and variation in the relative importance of issues among geographic regions. This program element serves a dual purpose in this report appearing here and in the discussion of the Water Quality Program (Chapter 4-C). However, this repetition does not imply a request for dual monitoring and research programs. In the context of ERP, the processes considered determine the productivity of the food web in the Bay-Delta system. Understanding these processes is critical to assessing the effects of CALFED actions on the Bay-Delta ecosystem. This section deals primarily with the deep-water pelagic system. Shallow-water systems are discussed below and the interchange between them mentioned in hydrodynamics.

The work team identified existing monitoring programs and provided a list of monitoring needs (see Appendix *VII.A.5* for details). A short list of general considerations for ongoing and new sampling programs includes:

- conduct continuous monitoring at established stations for physical and chemical variables in preference to, or supplemented by, shipboard monitoring,
- continue to use conductivity-temperature-depth sensor packages with additional sensors as needed,
- conduct studies to determine the effects of alternative sampling frequencies and schemes with regard to daily and spring-neap tidal cycles,
- develop a standard policy for storage and archiving of biological samples,
- incorporate new techniques of data acquisition and analysis as they prove their utility, and
- design a program to detect and track newly introduced species.

Another general consideration not included in the list but implicit in much of the plan was that monitoring had to be extended into more shallow-water areas than are currently monitored by ongoing programs. Shallow-water issues are discussed below and in Appendix *VII.A.6.*

The list of monitoring needs was very detailed, presenting specific recommendations for variables to be monitored under more generic topics. The more general topics include:

- measure basic physical variables ranging from precipitation to light attenuation in the water column,
- measure flow variables,

- measure chemical variables including nutrients and organic carbon,
- measure biomass and primary production of phytoplankton, benthic algae, and submerged aquatic vegetation,
- monitor microbial communities,
- monitor zooplankton species composition, biomass, and production,
- monitor sediment quality, and
- monitor species composition, abundance, biomass, and size distributions of benthic macroinvertebrates.

Twenty research topics were presented with a detailed justification for each. The research is needed to understand the processes underlying ecosystem responses observed in the monitoring data. This understanding is necessary to assess the contribution of CALFED actions to observed changes.

Bay-Delta System Productivity at Upper Trophic Levels (Appendix *VII.A.6*) – Declines in populations of many Bay-Delta fishes and larger macroinvertebrates (i.e. crabs and crayfish) have been observed in recent years. Many of these species support recreational or commercial fisheries with significant economic value. Others have been listed as threatened or endangered. CALFED goals emphasize increased populations of such species; therefore, monitoring and assessment is required. Three management activities were defined to guide design of the monitoring and research program:

1. management of harvested populations,
2. monitoring of status and trends species, and
3. assessment of general trophic dynamics among estuarine species.

Delta smelt and chinook salmon are mentioned in the plan but are addressed in more detail in single-species plans. This work team concentrated on the open-water pelagic system and emphasized aquatic species. Additional work on other organisms, particularly birds, may be needed. Most ongoing monitoring is conducted through the Interagency Ecological Program (IEP). Proposed new sampling to supplement ongoing IEP sampling was presented in the context of these three management activities.

Management of harvested species emphasized monitoring for striped bass, American shad, white and green sturgeon, various catfishes, Dungeness crab, and crayfish. Suggestions for additional monitoring included:

- determine catch per unit effort of adult American shad from the recently initiated Central Valley and Anadromous Creel Survey,
- collect and analyze data on adult American shad captured as part of other trapping and netting programs,
- increase tagging efforts for adult white sturgeon,
- increase trawling efforts in the lower Sacramento River and Suisun Bay for juvenile white sturgeon,
- assess monitoring methods for green sturgeon including use of fyke nets to capture young-of-the-year green sturgeon at the Red Bluff Diversion Dam on the Sacramento River and egg and larval sampling in the upper Sacramento River and Feather River, and
- increase striped bass monitoring efforts in shallow water areas to better understand juvenile habitat use.

Monitoring of status and trends species is intended to provide data on common species "representative" of groups of species rather than attempting to monitor all 165 species of fish that have been captured from the Bay-Delta system. Many of these species are already monitored adequately by existing programs. The species that were not adequately sampled because of habitat preferences or gear efficiencies were divided into three groups:

- Monitoring of species that mainly use the Bay-Delta as large-sized juveniles or adults could be improved by expansion of existing programs utilizing gill nets and trammel nets and recording data for all species captured rather than just program target species (e.g., striped bass). Additional new elements could include an index of fish health and a creel census.
- Monitoring of species using rocks, pilings, and other structures in brackish water areas will require selection of appropriate methods such as baited traps, bait angling, or creel census.
- Monitoring of species using habitats not sampled by present programs would involve adaptation of existing programs or design of new programs to sample these areas. For example, there is no sampling for fish occupying areas of intermediate depth between shallow-water channel edges and deeper-water midchannel stations.

Assessment of food chain dynamics requires sampling on the basis of three salinity regimes or regions and the species expected in each one. The regions are the Delta, brackish waters, and polyhaline waters. Monitoring would include diet studies for poorly understood species and monitoring of contaminant body burdens to examine bioaccumulation of contaminants through the food chain.

Research recommendations fell into four broad categories.

- Studies to improve the suggested monitoring program.
- Studies to develop new monitoring indicators.
- Studies to provide baseline data and methods that will be useful in detecting and assessing the effects of new introductions.
- Continually analyze and interpret data collected by the monitoring program to clarify and update research needs.

Measures of abundance, distribution, contaminant body burdens and diets were suggested as possible indicators. The research studies also identify the need for additional measurements on topics such as physiological condition that might serve as indicators.

Fish-X2 Relationships (Appendix *VII.A.1*) –The X2 standard is currently an important regulatory tool in the Bay-Delta system (X2 is defined as the distance in kilometers up the axis of the estuary to where the tidally averaged near-bottom salinity is 2 psu). The X2 standard is based on correlative relationships, derived from existing data, between X2 and abundances of some estuarine species. There is no consensus regarding the usefulness of the X2 standard for managing the Delta. The factors leading to lack of consensus range from disagreement over the statistical validity of the correlations underlying the standard to the fact that the ecological processes underlying the correlations have not been elucidated. Presumably with some understanding of the underlying cause and effect relationships encompassed in X2, more direct management actions might be possible for some species, which could result in lower water costs relative to the present X2 standard. Given the great importance of these issues in guiding management decisions, a small work team was formed to design a research program to elucidate the causes of the Fish-X2 relationships. The activities needed to monitor X2 and the relationships of organisms to X2 are encompassed under other ERP and other Common Program activities.

The suggested research program includes a detailed conceptual model, and a research plan including 30 possible studies. The program is designed in a stepwise manner so that the outcome of earlier studies determines whether subsequent studies are conducted. Many of the specific research studies require similar approaches and the research program will be organized around a common framework including consistent approaches for data analysis, hydrodynamic modeling, and population monitoring. Hydrodynamic and population monitoring were also recurring themes. The list of individual research projects is too detailed to summarize but seven general issues are the basis of the conceptual model.

- Variation in the physical environment with X2.
- Variation in retention and recruitment of organisms with gravitational and lateral circulation.
- Variation in retention and recruitment of organisms with circulation patterns in the low salinity zone.
- Variation in the extent or quality of physical habitat with X2.
- Variation in food supply with X2.
- Variation in entrainment effects with X2.
- Effects of X2 distinguishable by comparative studies of delta smelt and longfin smelt ecology, two species with similar life histories that appear to relate to X2 in very different ways.

Because this is primarily a research program, no indicators were identified.

Delta Smelt (Appendix *VII.A.7*) –Similar to the Fish-X2 relationships, the status of delta smelt and the response of the population to management actions are of high interest in the Bay-Delta system. Recovery of the delta smelt population is a high priority for CALFED as well as many Federal and State agencies and stakeholder groups. Given the high level of interest, a small work team was assembled to address monitoring and research needs for delta smelt.

The conceptual model summarized current knowledge and highlighted hypotheses for testing to clarify critical aspects of delta smelt life history. Existing monitoring programs, primarily IEP, covered most monitoring needs but several types of additional monitoring are needed.

- Improved monitoring and delineation of spawning habitat.
- Additional larval monitoring in the Delta and Suisun Bay.

The proposed research program included four general areas of emphasis:

- studies of basic biology and physiology,
- studies of habitat extent and quality,
- studies of growth and condition, and
- integrated monitoring studies of larval transport and recruitment processes.

Comparative statistics derived from delta smelt abundance and distribution indices might serve as a useful indicator of the performance of CALFED management actions. Given the high interest in delta smelt, such an indicator might be useful at a variety of levels.

Bay-Delta Shallow-water Habitats and Watersheds (Appendix *VII.A.2*) – Restoration or rehabilitation of Bay-Delta shallow-water habitats, primarily tidal wetlands and marshes, is a major component of the ERP as presently envisioned. Given the importance of these management actions to the CALFED program, a strong monitoring and research element is required. This component is very similar to the River Fluvial Geomorphology and Riparian Issues group because, although the general concepts of shallow-water ecosystem function are recognized, the outcomes of specific actions are still difficult to predict. An additional layer of uncertainty is added when benefits to specific native species are expected because the importance of shallow-water habitats to many native species has not been established.

The conceptual models emphasized the processes important to the maintenance of tidal flat and tidal marsh habitats. Emphasis was placed on the interaction of physical and ecological processes. A separate discussion of diked marshlands was also provided. These wetland types were emphasized because it appears that the most extensive ERP rehabilitation actions concern these types of habitat. Shallow open-water areas were not considered. Additional conceptual models may have to be formulated for other types of habitat that become the focus of ERP actions.

Because of the large area encompassing Bay-Delta wetlands, the many different types of habitats, and the number and extent of rehabilitation projects proposed, a traditional baseline monitoring design appeared impractical. Instead, the proposed design focuses on the types of habitats to be rehabilitated. The monitoring scheme is based on standardized project-level monitoring and comparisons of results with data from reference (least-disturbed) sites. A six-step outline for developing project designs and monitoring programs was presented.

- Set qualitative project goals.
- Develop a conceptual design for the project.
- Select quantitative performance indicators and monitoring elements that address the goals.
- Select stressor indicators and monitoring elements.
- Identify reference conditions and reference sites.
- Design the project-specific monitoring program.

Proposed performance and stressor indicators and the monitoring elements required to evaluate each indicator included the following:

- wetland integrity,
- shoreline change,
- channel morphology,
- wetland hydrology,
- tidal elevation,
- habitat patchiness,
- sediment characteristics,
- water quality,
- target population status including special status species identified by CALFED or other agencies,
- community structure of plants, invertebrates, fish, birds, and small mammals, and
- intensity of human activity.

Monitoring methods were not specified but presumably will be a mixture of methods used, similar to recommendations of the River Fluvial Geomorphology and Riparian Issues group. A separate element for Bay-Delta Shallow-water Fishes (Appendix *VII.A.3*) was submitted as a stand-alone product.

Research needs were derived from CALFED documents, other CMARP work team products and other existing programs in the Bay-Delta region, including the Bay Area Wetlands Ecosystem Goals Project and the Research Recommendations for the Regional Monitoring Strategy. General topics for focused research include:

- avian resources,
- fish resources (see Bay-Delta Shallow-water Fishes below),
- small mammals,
- marsh physical processes, and
- various needs for implementing and understanding marsh restoration.

Bay-Delta Shallow-water Fishes (Appendix *VII.A.3*) –Restoration of shallow-water habitats in the Bay-Delta region is a major component of ERP. It is assumed that such restoration will result in increased populations of desired fish species; however, supporting evidence for this assumption in the Sacramento-San Joaquin estuary is minimal. Monitoring and research are needed to determine if populations of native species actually respond in any way to habitat restoration projects and, if so, the processes that cause positive or negative responses.

The conceptual model incorporates several important ideas. Although most resident and migratory species of the Bay-Delta system can be found in shallow-water habitats at some time in their life cycle, such habitats are not necessarily of special importance to maintenance of the population. For other species, shallow-water habitats may be essential for completing all or part of the life cycle. The ecological function of shallow-water habitat varies among species. Important functions of shallow-water habitat could include spawning habitat, foraging habitat, refuge from predators, and near-shore migration corridors. Habitat use by fishes may vary seasonally and annually.

Two ongoing IEP programs provide sufficient coverage of the Delta, though some expansion of both surveys was suggested, and additional elements may be needed later as new monitoring and sampling methods are refined. Recommendations for project-specific monitoring emphasize pre- and post-project monitoring data and comparison of project results with results from non-project sites. Suggested variables included:

- presence/absence of species,
- relative abundance of common species,
- diets of common species,
- measurements of physiological variables ranging from condition factor to contaminant body burdens, and
- monitoring of the distribution and abundance of shallow water habitat types.

Two areas of research were prioritized.

- Develop sampling methods for shallow-water habitats.
- Resolve key questions regarding the use of shallow-water habitats by various species of fish and the importance of such use to population dynamics.

Sampling issues are presently being addressed by several IEP-sponsored studies and may be at least partially resolved in the near future. Most of the fish-use aspects are not presently being studied.

Chinook salmon (Appendix *VII.A.8-9*) – The separation of the Bay-Delta system and river system chinook salmon monitoring plans is artificial and was required by the organization of the report. In reality, these two portions of the plan will be tightly integrated into a single life-history-based plan across all habitats. Restoration of salmon runs is a major objective of CALFED. Monitoring and assessment of the effectiveness of CALFED actions is essential to evaluating success.

The suggested monitoring program stressed existing monitoring programs for juvenile abundance, distribution, and survival. Recommendations for new monitoring included:

- sample migrating juveniles as they exit San Francisco Bay,
- supplement existing studies of survival using coded-wire-tagged hatchery fish with similar studies using tagged wild fish if possible,
- monitor physical parameters including water quality and hydrodynamics in conjunction with the salmon studies, and
- monitor prey availability and fish community assemblages.

A detailed list of research topics was presented and prioritized. Six high priority areas of research were identified.

- Evaluate the importance of various types of lower river and Delta habitat to various salmon life history strategies and juvenile survival.
- Determine the causes of reduced survival in the central Delta compared to the mainstem Sacramento River.
- Assess various methodologies for determining race, basin or hatchery origin, and age structure.
- Assess new techniques for indexing the abundance and survival of emigrating juvenile salmonids. Implement the improved methods.
- Identify the influences of hydrodynamics on the survival and abundance of juvenile salmonids.

- Determine if food is limiting the survival of juvenile salmonids in the Delta.

Ten lower-priority issues were also identified (Appendix *VII.A.8*). Specific indicators were not suggested but various measures of abundance and survival might serve as indicators.

Steelhead (Appendix *VII.A.11*) –The river phase of the steelhead life history was addressed earlier under River Systems. New monitoring and research elements suggested for the Bay-Delta relate to evaluation of Bay-Delta water operations on steelhead emigration and rearing. For chinook salmon, this separation is a consequence of report organization and the two parts of the program are actually closely integrated. Specific needs mentioned included:

- determine the timing of smolt emigration through the Delta,
- determine the magnitude of diversion of smolts into the South Delta, and entrainment at the pumping facilities, and
- assess the effect of the loss of estuary rearing habitat.

Monitoring for Nonindigenous Organisms (Appendix *VII.A.14*) –This monitoring element primarily addresses the Bay-Delta ecosystem, generally acknowledged to be one of the most intensely invaded ecosystems in the world. The work team provided a justification for a separate nonindigenous species monitoring component rather than depending on the general monitoring programs already discussed above. Three fundamental objectives were identified for the monitoring program: 1) detect new introductions, 2) monitor the spread of recent introductions, and 3) identify and assess mechanisms of introductions. Two closely linked research purposes are understanding how introduced organisms affect the ecosystem and understanding the different factors that affect the success or failure of introductions. CALFED has already established a group to examine issues associated with non-native invasive species. This component of ERP-CMARP will be modified as needed to meet the needs of that group.

Three elements are needed in the monitoring program to meet the general objectives.

- Sampling must include habitats where introduced species are commonly first detected. Existing monitoring programs must collect, identify, and report new species.
- Organisms must be recognized as new introductions. This is an important problem for small organisms such as invertebrates and algae.
- A system to ensure accurate and timely identification of suspected exotic species is needed.

Although not explicitly identified, this monitoring element links to all other monitoring elements through collection of organisms. All monitoring programs should have procedures in place to identify and report suspected new non-indigenous species.

SUMMARY OF ERP RESEARCH NEEDS

The research needs identified for each monitoring element have already been summarized in the individual element sections (see Appendices *VII.A.1-14* for details). The needs identified are extensive. Some work teams have been very specific about what studies should be conducted. Other recommendations were very general. This difference is directly related to the existing levels of knowledge. Work teams addressing topics with existing (or recently completed) monitoring and research programs presented specific and focused research proposals. Work teams addressing topics relatively unstudied in the Sacramento-San Joaquin system were more likely to present general topics for research.

The extensive nature of the research recommendations also results from the CALFED objective to understand ecological processes to aid in adaptive management. General monitoring is inadequate to develop a complete understanding of these processes. Manipulative experiments or detailed study of natural situations are needed to meet the objective. Given the long list and potentially high cost of the research elements recommended, it is highly likely that CALFED will have to prioritize the research elements. Such a prioritization must strike a careful balance between specific needs in subject areas where much is known and general needs in subject areas where little is known. A major determinant of priority will be the importance of each topic to achieving CALFED goals and objectives.

LINKAGES AMONG ERP-CMARP COMPONENTS

Linkages among the various ERP program elements were addressed in each of the work team plans (Appendices *VII.A.1-14*). Consideration of these linkages result in a more integrated view of ERP-CMARP than the individual elements might suggest. All of the work teams recognized the efficiency provided by coordination of site selection and sampling activities.

Integration of river activities will largely center on the 40-50 long-term monitoring sites selected for the fluvial geomorphology component and sites where anadromous fishes are monitored by existing programs. In the Bay-Delta system, integration largely centers on existing monitoring programs with long-term data sets from established sampling networks. Sampling efforts can be coordinated for efficient use of available personnel and equipment. Such integration lends additional credence to comparisons among different data sets.

The division of the ERP-CMARP into River and Bay-Delta sections was the primary means of providing the work teams with manageable assignments and will not be carried into the implementation phase. Site selection, data collection, and data analysis will be integrated across the entire ecosystem, although appropriate methods may change as sampling moves from riverine to tidal habitats. For example, river resident fishes and anadromous fishes are sampled using different methods in rivers and estuaries, but if the sampling program is integrated in all other aspects, the data can be very valuable to understanding species and communities throughout the system. In some cases similar methods can be used across habitat types but the work team plans gave them different emphasis. For example, the use of aerial photography is appropriate for the identification and quantification of habitat types in both the rivers and the estuary; however, the work team addressing river fluvial geomorphology highlighted the use of aerial photography, while the Bay/Delta shallow-water habitat work team did not. This process of design integration will be one of the major challenges in refining CMARP.

The final version of the ERP-CMARP must integrate the data needs of other ERP teams as they are finalized. The need to include the species and habitat monitoring needs of the Conservation Strategy has already been mentioned. Clearly, all monitoring and research components will have to be designed to integrate general community monitoring and special-status species monitoring to the greatest extent possible. It is likely that some focused special-status species monitoring will be required. There is a CALFED group currently considering introduced species issues. The needs and recommendations of that group will have to be considered in the final design of the ERP-CMARP monitoring strategy for introduced species.

Linkages will also be necessary between ERP-CMARP and the Strategic Plan for the Ecosystem Restoration Program (Strategic

Plan), if ERP adopts the Strategic Plan wholly or in part. The Strategic Plan identifies 12 important issues and opportunities to consider in developing an adaptive management program, all of which will require monitoring and research. The issues are: 1) introduced species, 2) natural flow regimes, 3) channel dynamics, sediment transport, and riparian vegetation, 4) flood management as an ecosystem tool, 5) flood bypasses as habitat, 6) shallow-water habitats, 7) contaminants, 8) limiting factors, 9) fish-X2 relationships, 10) decline in Bay-Delta system productivity, 11) entrainment of fish at pumps, and 12) the importance of the Delta for chinook salmon. All but the entrainment issue are directly addressed by one or more ERP-CMARP or Water Quality Program elements. Entrainment issues are mentioned in a number of CMARP Bay-Delta system work team products. Programs directly focused on entrainment issues (at least at the Federal and State facilities) will likely be needed when the preferred alternative is selected and as part of real-time monitoring programs designed to guide project operations.

LINKAGES OF ERP-CMARP WITH OTHER COMMON PROGRAMS

The ERP-CMARP has linkages to other CALFED Common Programs (Chapter 4-K). Linkages of ERP-CMARP with elements of the Water Quality Program were the most commonly identified. These linkages included contaminants and general water quality measures important to organisms such as salinity. ERP actions to increase areas of wetland and other shallow-water habitats may also affect water quality by increasing the production of forms of organic carbon that can form disinfection byproducts during water treatment, an important human health consideration, and increasing bacteria-induced mercury methylation, which could have both ecosystem and human health effects. It was also recognized that bioassessments of fishes, invertebrates, and algae can be useful for both ecosystem and water-quality monitoring.

Linkages of the riverine components of ERP-CMARP with the Watershed Monitoring Coordination Program were commonly recognized. From an ecological perspective, the boundary between ERP and the Watershed Monitoring Coordination Program is completely artificial and it is possible that the boundary will blur in some cases, when CMARP is implemented.

The Water Transfers Program has potential ecological effects depending on the tools used. In-channel conveyance and diversion have implications for stream flow and hydrodynamics that may have to be addressed by ERP-CMARP. Less obvious are potential effects of conjunctive use of groundwater on ecosystems. Because groundwater and surface water are dynamically linked, groundwater withdrawals can have direct effects on stream flow of nearby streams and water levels in wetlands. The quality of groundwater entering these systems may also be important to ecological functions. The effects of ERP actions on water must be monitored. For example, assessments of evapotranspiration rates of restored wetlands and riparian forest might be necessary to understand effects of ERP actions on water transfers and water use efficiency. Possible effects on water quality for urban use of increased organic carbon loading from restored wetlands are also potentially important. There are also linkages between ERP and the Levees Program, through the Levee Habitat Mitigation Monitoring Plan (Levees Report, Appendix *VII.G.1*). Levees provide both terrestrial and instream habitat. Construction and maintenance activities to ensure levee integrity will be assessed for site specific and cumulative effects on the biological communities associated with them.

Perhaps the most important potential linkage between the ERP-CMARP and other Common Programs is the selection of a preferred alternative and the choice of storage and conveyance tools chosen to implement the alternative. Many of the monitoring and research programs will have to be tailored to assess the success and effects of those choices. For example, reconfiguration of Delta channels to provide protection for fish species will have to be assessed to determine if those benefits are realized. The monitoring and research elements summarized above should not be viewed as static. The elements of ERP-CMARP should continue to evolve to best meet CALFED needs as those needs are clarified.

LINKAGES OF ERP-CMARP WITH NON-CALFED PROGRAMS

The ERP-CMARP, as presently described, constitutes a massive effort in both scope and cost; however, additional prioritization of program components and coordination with existing programs will maximize efficiency and reduce cost considerably. The CMARP inventory effort has documented many programs spending considerable sums of money on monitoring and research (Table 2-2). Presumably, coordination of CMARP efforts with other programs will result in benefits to both groups. Such coordination could range from simply using compatible data formats, to supplementation of ongoing programs with CALFED funds, to implementation of new CMARP programs that will provide data useful to the non-CALFED programs. Many of the individual work teams recognized these linkages and included them in their recommendations (Appendices *VII.A.1-14*). Consideration of the Fish-X2 (Appendix *VII.A.1*) and delta smelt (Appendix *VII.A.7*) components provides a useful example of the levels of integration that may occur in the final CMARP design. These two components are very important in the context of CALFED goals and appear expensive. However, as recognized by the delta smelt work team, ongoing monitoring of the IEP is largely sufficient for CALFED delta smelt needs. The recommendations for additional monitoring could be met by supplemental funding to IEP from CALFED. Much of the proposed delta smelt research is already funded and ongoing under IEP or other funding, including CALFED Category III funds. Some aspects of the research program have not been initiated and this work could be expedited by making additional funds available. The research identified under the delta smelt component should be highly compatible with the delta smelt-longfin smelt comparative study included in the Fish-X2 research design. The research in the Fish-X2 component is not as well funded by ongoing programs but is designed in an efficient sequential manner that should keep costs to a minimum. The IEP annually funds a variety of special studies and some of the Fish-X2 research may qualify for such funding. Work done under the delta smelt component will fulfill some of the research needs. Ongoing hydrodynamics work is funded by IEP, the USGS Ecosystem Program, and California Department of Water Resources Planning. Coordination of those programs with Fish-X2 hydrodynamic data needs may be possible, perhaps with supplemental funding from CALFED. Presumably other cost savings can be found for these and other ERP-CMARP components; however, some components will likely have to be heavily funded if functioning programs do not exist and the component is deemed to be a high priority CALFED need.